Protected areas do not fulfil the wintering habitat needs of the trans-Saharan migratory Montagu's harrier

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ABSTRACT

Populations of migratory birds can be affected by events happening at both breeding and wintering grounds. The Sahel is a vast region holding a large number of wintering tans-Saharan migratory European birds, and current land-use changes there may represent a threat for these species. We used satellite tracking data from the migratory Montagu's harrier to evaluate habitat use of the species during the wintering season, and whether the current network of protected areas is effective to provide their habitat needs during that season. We also developed an ecological niche model for the species in Western-Central Sahel to check if the most suitable sites are included within current protected areas. Tracked harriers occupied a large region encompassing a total of eight countries. The most preferred habitats during winter were croplands and some natural vegetation habitats, especially grasslands. Protected areas only covered a small proportion of the overall wintering grounds of tracked harriers and the most suitable areas for the species in Western Sahel. Increasing the extent of preferred natural habitats within protected areas should benefit the conservation of this and probably other insect-eating raptors. However, substantial increases in extent and number of protected areas in sub-Saharan Africa are very unlike to occur. Conservation action in the region should therefore be mostly focused on improving land use planning and management outside protected areas, specially enhancing agricultural practices to make biodiversity conservation compatible with poverty alleviation. These can be chiefly targeted at an area of <20,000 km^2 of very suitable habitat for these species.

Key-words: *Circus pygargus*; ecological niche modelling; land uses; MaxEnt; raptors; Sahel.

1. INTRODUCTION

Populations of migratory birds can be affected by threats occurring at both breeding and wintering ranges, and passage areas (e.g. Newton, 2004, 2008). Decreases of breeding populations of several trans-Saharan migratory bird species in the European-African flyway have been linked to poor environmental conditions in the wintering areas (Newton, 2004, 2008; Sanderson et al., 2006; Zwarts et al., 2009). Thus, conservation programs aimed at protecting migratory species in their breeding grounds should take into account whether actions along the migratory routes and wintering grounds of the species are also necessary, since actions aimed solely at protecting breeding grounds are potentially doomed to fail (Martin et al., 2007).

The human population of Western Sahel countries (those comprised between the Sahara desert and African tropical forests) has increased from < 20 million people in the mid-20th century to > 60 million people currently (Zwarts et al., 2009). Associated with this, there has been an increase in food demands of the Sahelian population, which has resulted in an increase of croplands (e.g. Tappan and McGahuey, 2007), in spite of the Sahel being inadequate for agriculture due to its climatic conditions and poor soils (Breman et al., 2001). The area devoted to the cultivation of sorghum, millet and rice across eight Sahelian countries has doubled its extension from the early 1960s to present (see Zwarts et al., 2009 for a review). This has resulted in the deforestation of several areas and drainage of wetlands, creating new areas for agriculture, and triggering a cascade of other changes. For example, several bird species have modified their patterns of habitat use in these areas: birds traditionally associated with savannah habitats are now associated with low-intensive farming areas (e.g. Hulme, 2007). These changes are probably related to changes in availability of their prey, as several insect species that did not use wooded areas are now occurring at these new agricultural areas. This is the case of grasshopper species, which are a serious problem for crop production in the Sahel since 1974 (Zwarts et al., 2009). This massive increase in grasshopper populations has in turn promoted the use of insecticides (e.g. Everts, 1990), which affect non-target species and might provoke food depletion and even direct intoxication of birds (Mullié and Keith, 1993; Newton, 2004). These cascade effects represent a rising problem for the conservation of migratory European breeding birds, including raptors (Keith and Bruggers, 1998; Sánchez-Zapata et al., 2007).

More than 70 raptor species occur in the Sahel, including seasonal visitors. A great part of them inhabit open habitats and many are specialized in feeding on grasshoppers and locust swarms occurring in the region (Keith and Bruggers, 1998). Protected areas are beneficial for most raptor species occurring in the Sahel, although the current network of protected areas seems to be insufficient for the conservation of raptors, which have declined in last decades (Thiollay, 2006). Partly, this is due to several threats occurring inside protected areas, like human pressure or deforestation, especially in Western Sahel (Buchanan et al., 2009; Zwarts et al., 2009). On the other hand, protected areas may not cover the whole range of habitats used by many raptor species, as most protected areas in the region have been proposed to protect forest remnants or wetlands (Zwarts et al., 2009).

The Montagu's harrier (*Circus pygargus*) is a medium-sized migratory raptor which breeds in Europe and Asia, and has its wintering grounds in tropical Africa and India (Cramp and Simmons, 1980). The species is included in the Annex I of the new European Bird's Directive (2009/147/CE) and thus, special conservation actions to protect their habitats along its distribution area should be implemented to ensure its persistence. Overall in Europe, the species is increasingly linked to agricultural habitats for breeding and thus vulnerable to nest destruction during harvesting activities and other consequences of agricultural intensification (Arroyo et al., 2002; BirdLife International, 2010). Because of that, it is listed as Vulnerable in Spain and France, and Endangered in Portugal (Arroyo and García, 2004; Millon et al., 2004; Cabral et al., 2005), the main stronghold of Western Europe population. The use of satellite tracking has recently enabled the delimitation of the areas used by several European breeding populations during winter in the Sahel region (Limiñana et al., 2007; Trierweiler et al., 2007). While wintering in Africa the species feeds mainly on orthopterans, both migratory locusts and resident grasshoppers (Cormier and Baillon, 1991; Arroyo et al., 1995; Trierweiler and Koks, 2009). However, little is known about habitat use in winter in this species, which is of paramount importance in the face of ongoing land use changes in the Sahel.

In a recent review of the status of 127 Afro-Palaearctic migratory species (Zwarts et al., 2009), a total of 39 species (including raptors, storks, rallids and passerines) occupy similar areas as those used by Montagu's harriers during the wintering season, and 25 of them have experienced a steep decline in population numbers in the last three decades. Studying Montagu´s harriers can therefore contribute to understand and assess the threats to other trans-Saharan migratory bird species during wintering. Here we analyze habitat use in the wintering areas of adult and juvenile Montagu's harriers breeding in Spain, and evaluate the coverage provided by protected areas in the Sahel to the habitats preferred by the species.

2. MATERIAL AND METHODS

2.1 Bird tagging and tracking

The studied Montagu's harrier population established in the breeding area in the early 80s and population numbers had increased to ca. 150 breeding pairs by 2008. This population also shows one of the highest productivity recorded for the species in Europe (Limiñana et al., 2006; Soutullo et al., 2006). Between 2006 and 2008, a total of 30 Montagu's harriers (14 adults and 16 juveniles) were trapped during the breeding season in inland Castellón province (Eastern Spain) using dho-gaza nets and a stuffed Eagle owl (*Bubo bubo*) as a decoy. Birds were equipped with Microwave Telemetry satellite transmitters (9.5-gram Argos PTTs) fitted as backpacks using a Teflon harness (Limiñana et al., 2007). Weight of these transmitters represented between 2.6 and 3.9% of bird's body mass (mean = 3.2, SD = 0.4). All birds were released less than 30 minutes after capture. Satellite transmitters were programmed on a 6 hours ON / 16 hours OFF duty cycle for the first three months, and reset to a 10 hours ON / 56 hours OFF cycle for the following months to prevent battery drainage.

Overall, up to the winter 2008/2009, we obtained information on 25 complete wintering seasons (i.e., information recorded from the end of the autumn migration to the onset of the following spring migration), belonging to 15 tagged birds (eight tagged as adults and seven tagged as juveniles), nine of which were tracked for more than one wintering season. Our data set includes seven first wintering seasons for juveniles, four wintering seasons for sub-adult birds (birds in their second winter) and 14 for adult birds. From now on, by “wintering grounds” we refer to the region used by Montagu’s Harriers from all breeding populations during wintering in Africa, whereas we use the term “overall wintering area” to refer to the region encompassing the areas used during the study by the tracked individuals, and “individual wintering area” to refer to each individual wintering range (for every bird and wintering event).

2.2 Wintering grounds and fidelity to wintering areas

For every bird and year, the end of the autumn migration and the onset on the spring migration was defined following the procedures described in Limiñana et al. (2007, 2008). Locations in between these dates were assigned to the wintering season and plotted in ArcView 3.2. Only locations belonging to Argos location classes (LCs) 1, 2 and 3 were used in the analyses, as these are the most reliable to conduct habitat-use analyses (with nominal errors up to 1 km; Soutullo et al., 2007; Argos, 2008). The number of locations for each wintering season ranged between 48 and 169 (N = 25), giving a total of 2,853 wintering locations. The size of each individual wintering area was estimated as the 95% fixed kernel (Worton, 1989) of each season’s locations. Kernels were calculated using the Animal Movement extension for ArcView 3.2

(Hooge and Eichenlaub, 1997), and using the LSCV procedure (Silverman, 1986) to calculate the smoothing parameter (H). The size of every kernel polygon was calculated after projecting the shapes into an Equal-Area Cylindrical projection using Projector! extension for ArcView 3.2. We did not find any significant relationship between the number of fixes per wintering event and the estimated size of the home-range ($F_{1,23}$ = 0.21, P = 0.64, R^2 = 0.009). We also calculated the Minimum Convex Polygon (MCP) for every individual wintering area. We used one-way ANOVA in SPSS v.15 (SPSS Inc.) to test for differences in size of wintering areas related to harrier age or season. We estimated the size of the overall wintering area of our monitored birds as the 95% fixed kernel of all locations obtained during the study, and as the combined MCP (merging all the individual MCPs) (for habitat suitability analyses).

Finally, to evaluate fidelity to wintering areas we calculated the distance between individual wintering areas used by the same individual in consecutive seasons. To do that, we first calculated the centroid of every kernel polygon using the Center of Mass extension for ArcView 3.2 (Jenness, 2006), and then the distances between centroids of consecutive individual wintering areas. We used one-way ANOVA to test if these distances varied according to birds' age (i.e., whether distances between areas used first as juveniles and then as second-year birds, differed from the distances between areas used by adults). We also calculated the overlap (in km^2) between individual wintering areas used in consecutive years by the same individual.

2.3 Habitat use at the wintering grounds

We used the GlobCover global land cover map V.2.3 (ESA GlobCover Project; http://ionia1.esrin.esa.int/), available in a raster format of 300-m resolution and obtained from satellite images recorded during 2009. We rescaled this map to a 2.5 arc-minutes pixel size (i.e., roughly 4.5 x 4.5 km) by retaining the main cover (mode of the pixels within) as descriptor of the new pixels (e.g. Jiguet et al., 2011), and assigned a habitat type to every location recorded during the wintering season. To estimate habitat availability within the overall wintering area of tracked harriers we generated 5,000 random points within the combined minimum convex polygon (MCP), using the ArcView's Random Point Generator (Jenness, 2005), and then assigned the corresponding habitat type to every random point. To test whether habitats were used in relation to their availability, we used Monte Carlo methods (Limiñana et al., 2008; Soutullo et al., 2008a). To do that, a number of random points equal to the number of locations obtained within each habitat type (considering all birds together) were chosen at random from the 5,000 random points. This procedure was repeated 1000 times for each habitat type using Excel's "PopTools" add-in (Hood, 2006). To account for the effects of roosting sites on habitat use (which may overestimate the use of certain areas as a consequence of repeated night locations over the same habitat), the Monte Carlo analyses were conducted three times: one considering all locations (N = 2,853), one taking into account only day-time locations (N =1,247), and one using only night locations (N = 1,606). We considered as day-time locations those obtained between 06:00 and 19:00 local time, according to sunrise and sunset at wintering grounds' latitude, obtained from http://www.usno.navy.mil/USNO/astronomical-applications/data-services/rs-one-year-world.

We also conducted a compositional analysis to build a population-level ranking of habitat preferences (Aebischer et al., 1993). We evaluated individual use of available habitats within their wintering areas (third-order selection; Johnson, 1980) using the “adehabitat” package (Calenge, 2006) for R software (R Development Core Team, 2009). To do that, for each bird we compared the frequency of locations within each habitat, with the frequency of random points within each habitat type available within their individual wintering areas. To estimate habitat availability we generated 1,000 random points within the MCP of every individual wintering area, using the ArcView’s Random Point Generator (Jenness, 2005). For birds for which data on more than one wintering season were available, we estimated habitat availability as the mean of all year’s availability (i.e., mean number of points in every habitat). The analysis was performed using the package’s randomization test option, with 500 repetitions, replacing the values that were 0 in the matrix of used habitats by a value of 0.01 for computation, and setting 0.1 as the alpha level for the tests (Aebischer et al., 1993).

2.4 Wintering grounds and protected areas

Digital cartography of nationally recognized protected areas in the countries containing part of the overall wintering area of the studied population was obtained from the 2010 release of the World Database on Protected Areas (WDPA; UNEP-WCMC, 2010). When data on the boundaries of the protected areas were not available but a coordinate and extension of the protected area was indicated (this happened for two protected areas within the overall wintering area, both for the combined MCP and the 95% fixed kernel), we calculated circular buffers around the given coordinates, using those radii that rendered the indicated surface of a given protected area (Soutullo et al., 2008b; Jenkins and Joppa, 2009). We then calculated the percentage of actual locations within protected areas and identified the individuals which they belonged to and countries where they were located. We also identified all the protected areas that were included (at least partially) within the overall or the combined MCP, and calculated the overall extent that these areas actually protect in every country (the total area of these protected areas was used for these calculations). We tested whether harriers used protected areas in relation to their availability by performing a Chi-square test on a contingency table comparing the number of locations within and outside PA, and the number of a set of 5000 random points within the combined MCP that fell within or outside PA. Finally, to evaluate the habitats included within these protected areas, we generated 1,000 random points within the boundaries of the protected areas including part of the combined MCP, and assigned a value of habitat to every point. We then compared the percentage of points in every habitat within and outside protected areas using the standardized residuals of a Chi-square test (Zar, 1999). Habitat availability outside protected areas was calculated from a new set of 5000 random points within the combined MCP that fell outside protected areas.

2.5 Ecological niche model of wintering Montagu’s harriers in Western Sahel

Additionally, to test the efficiency of protected areas network in Western Sahel for the Montagu’s harrier at large (not only for the monitored individuals), we used satellite tracking data to model the ecological niche of the species in this region (Marini et al., 2010; Jiguet et al., 2011). We limited our model to Western and Central Sahel (from -19 to 16ºW and from 5 to 21ºN) since Montagu's harriers breeding in Eastern Europe (up to Poland and Belarus) winter there (Trierweiler and Koks, 2009). To build the model we used MaxEnt software, which allows a powerful approach that does not need true-absence data (Phillips et al., 2006; Elith et al., 2011), as is the case when using information from satellite-tracked birds. As presence data, we randomly selected ten satellite day-time locations per bird and wintering season (i.e., a total of 250 presence data), setting a random selection of 25% of data to test the model. As predictive variables of the ecological niche we used 11 environmental grid layers at a resolution of 2.5 arc-minutes (i.e., 4.5 x 4.5 km) encompassing the abovementioned region. These included the GlobCover land-uses layer mentioned above, eight climatic variables obtained from the BioClim database (http://cres.anu.edu.au/outputs/anuclim/doc/bioclim.html) related to temperature and precipitation, which are well-known to be adequate to model bird's distribution (e.g. Araújo et al., 2009; Jiguet et al., 2011), and two topographic variables. The climatic variables used were: 1) mean annual temperature, 2) temperature seasonality (standard deviations of monthly mean temperatures), 3) maximum temperature of the warmest month, 4) minimum temperature of the coldest month, 5) annual precipitation, 6) precipitation of the driest month, 7) precipitation of the wettest month, and 8) precipitation seasonality (coefficient of variation of monthly precipitation). The two topographic variables, slope (in degrees) and aspect (as a continuous variable between 0 and 360º), were derived from the Digital Elevation Model obtained from the BioClim database, using MiraMon-GIS (Pons, 2008). Both slope and aspect were calculated according to the eight surrounding pixels for every grid cell, and regarding aspect, resulting pixels with a slope less than 2º were considered as flat (no aspect). Probability of harrier presence in every grid cell was then obtained according to a logarithmic scale between 0 and 1. We considered as "suitable" areas for the species those cells for which probability of presence were higher than 0.5; additionally, we also defined as "very suitable" areas those for which probability occurrence was higher than 0.75. Resulting GIS shapes were projected (as mentioned above) to calculate the actual extent of suitable and very suitable areas for Montagu's harriers in Western Sahel, as well as to calculate the extent of these areas that are included within protected areas. No protected areas indicated only with a coordinate and extension occurred within suitable or very suitable areas for the species at their wintering grounds.

3. RESULTS

3.1 Wintering grounds and fidelity to wintering areas

All of the tagged harriers wintered in Western Sahel region, across an area comprised between 10–17ºN and 16–0ºE, with an overall extension of 322,411 km^2 (95% fixed kernel; Fig. 1a). This area included a total of eight countries (Senegal, Gambia, Guinea-Bissau, Mauritania, Mali, Burkina Faso, Ghana and Guinea). Presence in Guinea, Guinea-Bissau and Ghana was however marginal. No locations were actually recorded in Guinea, but individual wintering areas of some tracked birds included part of this country. Guinea-Bissau and Ghana included only 9 and 2 locations, respectively. Most of the locations were recorded in Mali and Mauritania (1,202 and 908 out of 2,853, respectively).

Mean extension of individual wintering areas (95 % fixed kernels) was ca. 26,500 km^2 (SD = 25,022 km^2, N = 25; Table 1). These individual wintering kernels were formed by a varying number of sites, ranging from one to six, that were used sequentially throughout the winter. The most common pattern was having two or three sites. We found no significant differences in size of wintering areas related to age ($F_{2,22}$ = 0.275, P = 0.762) or wintering seasons (2006/2007, 2007/2008 and 2008/2009; $F_{2,22}$ = 1.822, P = 0.185). Given that the overall wintering area used by tracked Montagu's harriers is ca. 2000 km long (see Fig. 1a), individuals showed a relatively high between-year fidelity to their wintering areas, with the distance between centroids of individual wintering areas used in consecutive years ranging between 13.3 and 93.4 km (mean = 47.5 km, SD = 29.4, N = 10). These distances did not vary among birds of different age ($F_{8,1}$ = 0.018, P = 0.897), with second-year birds using roughly the same area they used for the first time. Additionally, the overlap of individual wintering areas used by the same individual in consecutive years was high, and sometimes a smaller wintering area completely laid within a larger area used in the previous or following year (Table 1).

3.2 Habitat use at the wintering grounds

When taking into account all locations from tagged harriers, habitats most frequently used were croplands: most locations (ca. 66%) occurred in habitat types that included croplands, which were used more frequently than expected from their availability (Table 2). Mosaics of grasslands and other natural vegetation (shrubs or forest) and grasslands in regularly flooded areas were also positively selected, although the actual number of locations recorded at these habitats was low (Table 2). In contrast, herbaceous vegetation (grasslands and savannahs), forests and shrublands were used less than expected from their availability (Table 2).

When considering only day-time or only night-time locations, the same general pattern was observed, although some differences were observed. Sparse vegetation was positively and significantly selected during daytime, but negatively during night-time (Table 2), suggesting that this habitat may be mostly used for foraging and avoided for roosting. Bare areas were positively selected at night-time, but used according to availability during day-time, and mosaics of natural vegetation with cropland were positively selected during daytime, but used according to availability at night-time (Table 2). This also suggests that their main use was for roosting and foraging, respectively. On the other hand, no pattern in individual's use of different habitats within their wintering areas (third-order selection) was observed (lambda = 0.0048, P = 0.267).

3.3 Wintering grounds and protected areas

Considering the combined MCP, only 10.8% of its extent was included within a total of 124 protected areas, which had an overall extension of 83,197 km^2 and a mean size of 671 ± 1,978 km^2 (Table 3). This percentage was even lower (5.8%) when considering the 95% fixed kernel as the overall wintering area, which included a total of 68 protected areas with an overall extension of 27,149 km^2 and a mean size of 399.3 ± 1,111 km^2 (Table 3). Regarding the actual locations, only 96 of them (3.4% of the total) were recorded within protected areas. Those locations belonged only to five individuals, with one (a juvenile) accounting for 90 of them. When comparing the proportion of fixes inside and outside protected areas, as compared with random points within the combined MCP, harriers appeared to use protected areas less than expected at random (χ^2_1= 142.7, $P < 0.0001$).

According to the ecological niche model, a total of 127,066 km^2 were considered as suitable areas for the species in Western Sahel, but only 7,412 km^2 (5.8%) were included within a total of 56 protected areas in that region. When considering very suitable areas, these represented a total of 17,880 km^2 in Western Sahel and 715 km^2 (4%) were included within a total of 12 protected areas (see Fig. 1b and 1c). The variables that were important when modelling the ecological niche of Montagu's harrier in Western Sahel were: habitat (which explained 26.3% of harrier's occurrence), annual precipitation (26%) and precipitation seasonality (17.9%); all the remaining variables explained less than 10%.

Protected areas at the wintering grounds of Montagu's harriers (Fig. 1c) included a variety of habitats, including those used by harriers. Nonetheless, rainfed croplands and cropland mosaics, which were widely used and positively selected by harriers, were significantly less common inside than outside protected areas, as also happened with sparse vegetation areas or grasslands on flooded areas, other favoured habitats (Table 2). In contrast, habitats that were mostly avoided by harriers like open forests and shrublands, were significantly more common inside than outside protected areas (Table 2).

4. DISCUSSION

Results obtained in the present study show that 1) Montagu´s harriers from the same breeding area distribute themselves across a very large wintering ground, although individual birds use a relatively small area and are faithful to the same wintering area in consecutive years; 2) their preferred habitats during winter are mainly croplands particularly when mixed with other natural-vegetation open areas (mainly grasslands); 3) suitable wintering areas occur mostly outside protected areas; and 4) protected areas contain a significantly lower proportion of their preferred habitats during the wintering season. Consequently, the protection of this species heavily relies on effective measures implemented outside protected areas, mainly related to enhance agricultural practices that are compatible with biodiversity.

Montagu´s harriers tracked in this study preferably used croplands during the wintering season. Habitats containing natural grasslands were also positively selected particularly when they were interspersed with croplands, but natural habitats containing shrublands or forests were mostly used below their availability (Table 2). This preference for cultivated areas in winter, also observed during the breeding season, suggest that birds may be exposed to similar risks during both periods (Arroyo et al., 2002, 2004). Furthermore, threats that individual birds may experience are probably consistent over time, since fidelity to individual wintering areas has been found to be high. Agriculture development has been shown to have a negative impact on biodiversity in several areas of Africa (Darkoh, 2003). Recent agricultural expansion in the Sahel has relied on the clearing of natural vegetation areas such as forests and several types of shrublands, which are mainly avoided by foraging harriers (as seen in our results). Yet, whereas the deforestation of several areas in the Sahel may have initially resulted beneficial for Montagu's harriers, as new open areas were created, subsequent agriculture development in these cleared areas results in several threats affecting both resident and migratory bird species (e.g. Newton, 2008). One of these threats is the use of pesticides to control locust and grasshopper populations (Keith and Bruggers, 1998). Although current pesticide use in the Sahel is likely to be less intensive than in Western Europe, an increasing use may represent a threat for this and other insect-eating species as pesticides may severely alter the total amount of food available (e.g. Mullié and Keith, 1993). Additionally, direct lethal or sub-lethal effects of pesticides on harriers cannot be excluded (Keith and Bruggers, 1993).

Our results also show that the current network of protected areas is insufficient to protect a significant part of the areas used by Montagu's harrier, or those that are potentially suitable for the species in Western Sahel. This inefficiency of protected areas also applies, at a larger scale, to conservation of several bird species across Tropical Africa (De Klerk et al., 2004; Beresford et al., 2011). In the case of Montagu´s harriers, this poor performance is aggravated by a combination of three factors. First, although there are many protected areas in the region, most of them are of relatively small size, even smaller than individual wintering areas. Similar results have been also found in the breeding grounds for the Montagu´s harrier (Guixé & Arroyo, 2011). Secondly, the distribution of protected areas in the Sahel region is not homogeneous. They are mostly located in Senegal, and are nearly absent in countries like Mauritania or Mali, which hold a large number of migratory bird species during the winter (Zwarts et al., 2009), including Montagu´s harriers (Fig. 1b). Finally, habitats preferred by Montagu's harriers during the wintering season are not well represented within existing protected areas. All these three factors combined indicate that the protection in winter of Montagu's harriers mostly relies on effective measures implemented outside protected areas, related to enhance agricultural practices that are compatible with biodiversity conservation. This poor efficiency of protected areas from Western Sahel in protecting the wintering range of Montagu's harrier could be also generalized to other wide-ranging trans-Saharan migratory birds that use preferentially agricultural areas at their wintering grounds, including several insect-eating raptor species (Thiollay, 2006; Zwarts et al., 2009; Anadon et al., 2010).

In any case, protected areas in Western Sahel contain sparse vegetation and several types of natural grassland mosaics that are also important as wintering habitat for Montagu's harriers and probably other raptors of similar ecological needs (although not necessarily in even equal proportions to what is found outside PA). Tropical and temperate grasslands and savannahs are ecosystems of high conservation concern that are globally threatened due to land use changes and underrepresented within current protected areas (Hoekstra et al., 2005; Lee and Jetz, 2008; Soutullo et al., 2008b). Therefore, ensuring the protection of these habitats or increasing their availability within extant protected areas should benefit the conservation of these species, given the high risk of land conversion to agricultural uses in Western Sahel, even within protected areas, which are declared but not effectively managed (Blom et al., 2004; Zwarts et al., 2009). Expanding the protected areas network to encompass a large extent of these open-vegetation habitats should theoretically benefit these species, but this is very unlike to occur in the next years in sub-Saharan countries (McDonald and Boucher, 2011), with some of the lowest Human Development Indices (HDI; United Nations Development Programme, 2010). Therefore, conservation of this and probably other species heavily relies on measures taken outside protected areas (e.g. optimizing crop management to reduce negative inputs without negatively affecting food production). This represents an invaluable opportunity to advance in finding common grounds for biodiversity conservation and poverty alleviation (Mellor, 2002; International Institute for Environment and Development, 2010).

5. CONCLUSIONS

Agriculture expansion to cope with the needs of an increasing human population in sub-Saharan Africa represents a conservation problem in terms of habitat loss for many species. Although current protected areas protect some of the natural habitats used by Montagu’s harriers and other raptors that feed at open habitats, suitable habitat for these species are largely underrepresented in protected areas. Moreover, less than 6% of the areas suitable for Montagu’s harriers are located within protected areas. This means that these species are not currently benefiting from the current network of protected areas, and are vulnerable to changes occurring outside them. In a general context for Montagu’s harriers, problems occurring in the breeding grounds in Europe decreasing the productivity of the species are likely to have a more significant effect on population trends than those occurring in the wintering grounds affecting adult survival (Trierweiler, 2010). However, negative effects to harriers at their wintering grounds may represent carry-over effects on productivity, and any decrease in adult survival due to degradation in wintering conditions would have direct and dramatic effects on populations (Norris, 2005). Therefore, it seems important to maintain or improve conditions for this and other species during winter. Yet, the main threats to protected areas in Africa (deforestation and agriculture expansion, Fishpool and Evans, 2001), may not be as important for these species as agricultural development or potential intensification processes, including increases in pesticide use. Consequently, conservation of these species mostly depends on actions and schemes implemented outside protected areas, aimed at making agricultural expansion and biodiversity conservation compatible. Focusing these conservation efforts in a small and concrete range of suitable areas (e.g. the 17,880 km^2 of most suitable areas for Montagu's harrier presented here; Fig. 1b) would be beneficial for a large number of insect-eating birds using these sites during the wintering season. For European countries to fulfil some of their directives on biodiversity conservation (e.g. the Bird's Directive) they need to consider investing in the protection of natural habitats far away from their boundaries, and the promotion of better agricultural practices in developing countries (Kirby et al., 2008). This is particularly relevant in the Sahel, a region highly dependent of international cooperation to improve people's life expectancy and well-being.

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TABLES

Table 1. Data on wintering areas of 15 Montagu's harriers (*Circus pygargus*) tracked by satellite telemetry. Distance between years indicates the distance between the centroids of wintering areas used in consecutive years. The overlap area indicates the extent of the area shared in consecutive years by the same bird.

Bird ID#	Age at tagging	Wintering season	Size of wintering area (km^2)	Number of wintering locations	Distance to previous year	Overlapped area (km^2)
34474	Adult	2006/2007 2007/2008	38.48 2287.67	76 59	36.25	38.48
39706	Adult	2006/2007 2007/2008	12,060.38 850.14	101 107	92.67	800.49
39707	Adult	2006/2007 2007/2008	6,442.92 24,122.34	102 73	93.44	5,425.60
39710	Adult	2006/2007 2007/2008 2008/2009	42,778.82 32,237.47 48,727.46	104 95 48	18.09 / 13.27	31,589.68 / 30,486.81 / 35,768.78
39715	Adult	2006/2007 2007/2008	290.15 1,790.74	146 138	25.11	280.23
80404	Adult	2008/2009	32,762.76	115	-	-
80406	Adult	2008/2009	85,198.96	158	-	-
80407	Adult	2008/2009	34,047.70	103	-	-
34700	Juvenile	2007/2008	31,626.94	169	-	-
34702	Juvenile	2007/2008	5,686.64	135	-	-
34706	Juvenile	2007/2008 2008/2009	15,280.74 10,112.91	139 92	57.48	7,086.95
34707	Juvenile	2007/2008 2008/2009	57,066.95 36,434.28	144 151	35.93	36,433.23
34716	Juvenile	2007/2008 2008/2009	14,705.85 13,749.75	146 123	32.89	9,387.62
34718	Juvenile	2007/2008 2008/2009	78,542.51 66,688.77	113 89	70.32	42,226.35
80412	Juvenile	2008/2009	8,543.85	127	-	-

Table 2. Habitat in wintering grounds included within the combined MCP obtained for 15 satellite-tracked Montagu's harriers. The percentage of locations in each habitat type is indicated (for all locations and only for day-time or night-time locations). p-all: P-value for the comparison between random points within the combined MCP and all locations. p-day: P-value of the comparison between random points and day-time locations. p-night: P-value of the comparison between random points and night-time locations. (+) and (-) indicate whether habitat are preferred or avoided by harriers, respectively. p-PA: P-value for the comparison between points inside and outside protected areas (PAs).

Habitat type (GlobCover)	**% of random points within the MCP**	**% locations of birds (all locations)**	**% locations of birds (day-time only)**	**% locations of birds (night-time only)**	**p-all**	**p-day**	**p-night**	**% random points inside PAs**	**% random points outside PAs**	**p-PA**
Rainfed croplands	8.32	13.70	11.23	15.63	<0.001 (+)	<0.001 (+)	<0.001 (+)	6.96	9.67	<0.001
Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	19.76	27.48	26.62	28.14	<0.001 (+)	<0.001 (+)	<0.001 (+)	17.00	20.29	<0.05
Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	21.40	24.85	29.11	21.54	<0.001 (+)	<0.001 (+)	>0.4	17.50	21.22	<0.02
Open (15-40%) broadleaved deciduous forest/woodland (>5m)	1.20	0.42	0.16	0.62	<0.001 (-)	<0.001 (-)	<0.001 (-)	6.56	0.67	<0.001
Mosaic forest or shrubland (50-70%) / grassland (20-50%)	4.70	6.45	6.58	6.35	<0.001 (+)	<0.001 (+)	<0.003 (+)	6.06	4.80	>0.1
Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)	14.98	3.75	2.25	4.92	<0.001 (-)	<0.001 (-)	<0.001 (-)	21.07	13.48	<0.001
Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	20.58	14.79	14.84	14.76	<0.001 (-)	<0.001 (-)	<0.001 (-)	19.88	20.15	>0.8
Sparse (<15%) vegetation	2.86	3.08	5.05	1.56	>0.1	<0.001 (+)	<0.001 (-)	1.39	3.33	<0.002
Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	0.82	0.21	0	0.37	<0.001 (-)	-	<0.015 (-)	0.70	0.99	>0.4
Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	1.14	1.93	1.60	2.18	<0.001 (+)	<0.03 (+)	<0.001 (+)	0.00	1.07	<0.003
Bare areas	3.02	3.33	2.57	3.92	>0.06	>0.8	<0.005 (+)	1.69	2.82	>0.06
Other habitats	0.82	0	0	0	-	-	-	0.60	0.75	-
TOTAL NUMBER OF POINTS	5000	2853	1247	1606				1000	5000	

Table 3. Size and number of protected areas (PAs) included (at least partially) within the combined MCP obtained from the 15 Montagu's harriers tracked in this study (upper panel), and within the 95% fixed kernel of these locations (lower panel). Information is given according to IUCN categories of protected areas (when available at the WDPA database), and for all protected areas together.

	IUCN Category II		*IUCN Category IV*		*IUCN Category Not Known*		**All Protected Areas**	
Country	Area (km^2)	Number of PAs	Area (km^2)	Number of PAs	Area (km^2)	Number of PAs	Area (km^2)	Number of PAs
Burkina-Faso	887	1	18,220	1	2,236	17	21,343	19
Gambia	29	1			186	2	215	3
Ghana					94	1	94	1
Guinea	279	1			802	2	1,081	3
Guinea-Bissau					5,482	10	5,482	10
Mali	3,948	1	3,580	2	2,585	5	10,113	8
Senegal	8,265	1	11,773	2	24,831	77	44,869	80
TOTAL	**13,408**	**5**	**33,573**	**5**	**36,216**	**114**	**83,197**	**124**

	IUCN Category II		*IUCN Category Not Known*		**All Protected Areas**	
Country	Area (km^2)	Number of PAs	Area (km^2)	Number of PAs	Area (km^2)	Number of PAs
Burkina-Faso	887	1	1,742	14	2,628	15
Gambia	29	1	186	2	215	3
Guinea	279	1			279	1
Mali	3,949	1			3,949	1
Senegal	8,988	2	11,090	46	20,078	48
TOTAL	**14,131**	**6**	**13,018**	**62**	**27,149**	**68**

FIGURE CAPTIONS

Fig. 1. Wintering areas of Montagu's Harrier in the Sahel. (a) Dots indicate all the locations recorded for the 15 birds tracked during the study period (see text for details). The overall Minimum Convex Polygon (MCP) encompassing all the locations obtained is indicated with a solid line; kernel polygons of all these locations are also illustrated (light-grey: 95% fixed kernel, and dark-grey: 50% fixed kernel). (b) Ecological niche model of wintering Montagu's harriers at Western Sahel. Probability of presence in 4.5 x 4.5 km pixels is indicated with a three-category scale. (c) Current network of protected areas in western Africa.

FIGURES

Fig. 1